July 1979

(NASA-CR-158751) AIRBORNE INFRARED AND SUBMILLIMETER ASTRONOMICAL POLARIZATION MEASUREMENTS AT DIFFERENT WAVELENGTHS Final Technical Report, 1 Oct. 1977 - 31 Dec. 1978 (Cornell Univ., Ithaca, N. Y.) 7 p

N79-27044

HC A02/MF A01

Unclas

G3/89 27863

CORNELL UNIVERSITY

Center for Radiophysics and Space Research

ITHACA, N. Y.

FINAL TECHNICAL REPORT

to the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

on

NASA Grant NSG 2262

AIRBORNE INFRARED AND SUBMILLIMETER ASTRONOMICAL POLARIZATION MEASUREMENTS AT DIFFERENT WAVELENGTHS

October 1, 1977 to December 31, 1978

Principal Investigator: Martin Harwit

Airborne Infrared and Submillimeter Astronomical

Polarization Measurements at Different Wavelengths

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Introduction

Observations of the Kleinmann-Low region of the Orion Nebula in the wavelength range from 1 to 13μm have been known, for some time, to reveal significant polarization (Loer, Allen and Dyck 1973, Breger and Hardorp 1973, Dyck et al., 1973, and Dyck and Beichman 1974). Our group at Cornell University therefore decided to search for polarization at wavelengths greater then 15μ. One paper giving our results has already appeared in print (Gull et al., 1978, hereafter Paper I, and references therein; see Appendix). These early observations were consistent with minimal ($\lesssim$ 2%) polarization in the far infrared. More recent results that are being prepared for publication show greater sensitivity, but persistently low polarization.

The 1 - 13μm polarization (up to ∿26% at 1.6μ and ∿15% at 10μm at position angles of ∿85 - 115°) is believed to be due to absorption by aligned grains; a summary of theoretical models was presented by Dennison (1977), who had participated in some of the earliest observations while a student at Cornell. The detection of the absorption-induced polarization from a region where the optical depth is $\tau_{9.7\mu m}$ ∿3 and the polarization is about 15% at 87° suggested the strong possibility that one might expect a polarization of $\lesssim$ 5% at an orthogonal angle of ∿-3° (117°) from the thermal emission by the grains at $\tau_{\lambda>40\mu m}$∿1. In this final report we present our most recent, thus far unpublished, observations bearing on the question of this long wavelength polarization.

Observations

During February 1978 we carried out far infrared polarization measurements on a number of sources using the instrument described in Paper I mounted at the bent cassegrain focus of the Kuiper Airborne Observatory's 90 cm telescope. Briefly, the system utilizes a liquid-He cooled Ge:Ga photoconductor, four cooled broad band filters (Table I, from Paper I), and a Cambridge Physical Sciences Model IGP 223 polarizer. A 4 mm aperture defined a ∿ 1' beam on the sky, and the telescope's oscillating secondary produced two beams separated by ∿ 1.9'. About 2 hours of data on Orion were acquired on each of two flights (16 and 17 February) compared to the one hour of data discussed in Paper I. More careful calibration on Jupiter (assumed to be unpolarized) were obtained on both nights. (A number of additonal objects were studied to varying lesser degrees and will be discussed in a separate paper. These included IRC +10216, the galaxy M 82, and two H II regions. Each of these sources gave a measurable flux in at least one of our bandpasses, and we hope to undertake additional, more detailed observations of these sources in the future.) The data on Orion and Jupiter for Filters 2-4 are presented in Fig. 1; the lower quality Filter 1 data appeared random on Orion and have been omitted from the present discussion.

Data acquisition procedures were similar to those described in Paper I except that during the February 1978 flights we oversampled by taking measurements every 22.5° instead of the required 45°. The experiment was entirely automated for these flights in that the on-board computer system (ADAMS) nodded the telescope, rotated the polarizer, and handled

all of the data acquisition and display tasks in-flight. The focal plane camera was monitored visually for the purpose of making minor guiding corrections to the computer tracking and to correct for the (small) field rotation during the flight leg. As discussed in Paper I, the signal-to-noise on each measurement was quite high for filters 2,3, and 4 (20 or better for the data reported here), but the level changes between successive runs were sometimes as large as 10%. (This is still in contrast to the much larger variations reported in Paper I.) Thus, it is the problem of drifts, believed to be due to changes in the atmospheric transmission, that introduces the largest uncertainty into the results.

Results

After subtracting the instrumental polarization as measured on Jupiter and averaging the data from both flights we find the following polarizations:

Filter 2 1.2% $\pm \sim 1\%$ at 130° (28-48μm)

Filter 3 2.2% $\pm \sim 1\%$ at 142° (44-72μm)

Filter 4 1.4% $\pm \sim 1\%$ at 126° (71-115μm)

These become 1.4, 2.4, and 1.6%, respectively, after we compensate for the polarizer efficiency (Paper I). Due to the relatively small polarizations observed, the angles are not well determined; a reasonable error in angle is $\pm 15^{\circ}$. Although these detections are all grouped rather closely together in amplitude and direction, we must recognize that the size of the scatter, while not randomly distributed around the calibration points, is of the order of the size of the polarizations under discussion here. Thus, we must conclude that we have an accuracy of $\sim 1\%$ and that our results are consistent with no polarization at longer wavelengths. One should bear in mind that the KAO is not specifically designed for polarization observations and that the bent cassegrain configuration, the dichroic beamsplitter, and the far infrared filters and windows can all introduce some polarization. However, the results presented here suggest that for sources observed with comparable S/N even an instrumental polarization as large as ours can be subtracted out to give meaningful results (for>1% source polarization levels).

Discussion

In Paper I we gave a number of possible explanations that could reconcile the high polarization observed by Beichmann and Dyck at 10 μ with the far lower polarization we observe. These are i) gas and dust may be in turbulent motion in the Kleinmann-Low Nebula, with only the surface layers opaque to shorter wavelength radiation non-turbulent. ii) The interior of the Nebula may be in thermal equilibrium locally between gas and dust. In that case there is no heat engine that drives alignment of grains even in the presence of substantial magnetic fields. iii) The direction of the magnetic field may change throughout the cloud, so that a line of sight through the cloud encounters almost randomly oriented grains. Finally, the Nebula may be optically thick at the wavelengths observed--a result which is consistent with the identity of brightness and color temperature in the Nebula at far infrared wavelengths.

The only observations inconsistent with this last explanation are 45μ observations by Papoular et al. (1978), who claimed that excess radiation in a broad band at 45μ should be associated with emission by amorphous ice grains. If these grains were aligned, we would have expected enhanced polarization at these wavelengths above the level calculated earlier from the 10μm observations. Again, if their identification is correct, this would suggest the grains are not aligned.

Participants in the Work Conducted as Part of the Present Project:

Martin Harwit, Principal investigator

Dr. Ray W. Russell, Postdoctoral research associate

George E. Gull, Research aide

Gary Melnick, Graduate research assistant

Budgetary Status at the Termination of the Contract:

At the termination of the grant, the budgetary status was $18.00.

Acknowledgements

We thank the staff of the KAO for their excellent support and F. Briggs for discussions of the data reduction programs.

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TABLE I. Filter characteristics.

Filter number	Filter components	Approximate waveband of maximum transmission (μ)
1	(a) 1.3-mm-thick KRS-5 with 0.01-mm polyethylene on each side (b) 2-mm-thick KCl (c) A 15.7–26.7-μ interference filter on a silicon substrate	16–26
2	(a) 3–16-μ diamond dust on polyethylene film, applied to 1-mm-thick sapphire (b) 1-mm-thick AgBr	28–48
3	(a) Same KRS-5 filter as above (b) 1.5-mm CaF_2 with 0.01-mm polyethylene on each side	44–72
4	(a) 2.2-mm BaF (b) 0.1-mm black polyethylene	71–115

APPENDIX

"Far-Infrared Polarization of the Kleinmann-Low Nebula in Orion"

G. E. Gull, J. R. Houck, J. F. McCarthy, W. J. Forrest and M. Harwit